Petrotek

**Technical Report**

# EWS No. 4A Well (API #05-123-44047) MARCH 2017 STEP RATE TESTING CLASS II COMMERCIAL INJECTION WELL

EWS 4 DJ Basin LLC
T2N, R63W, Section 17: Weld County, Colorado

April 7, 2017

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TECHNICAL REPORT
2017 CLASS II WELL TESTING
EWS 4 DJ Basin LLC
EWS 4A Well (API #05-123-44047)

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## 1.0 INTRODUCTION

This report summarizes the March 16, 2017 reservoir testing activities performed at the EWS 4 DJ Basin LLC EWS 4A well site in Weld County, Colorado. The primary objectives included performing a step-rate test with results of the test analysis intended to satisfy the request of the Colorado Oil and Gas Conservation Commission to evaluate current conditions. The field operations included a step-rate injection test utilizing twelve 30-minute injection steps that ranged from 1.0 to 14.3 barrels per minute (bpm).

The EWS 4A Class II commercial disposal well is completed in the DJ Injection Zone including the Lyons through upper Fountain Formations. The vertical well was completed from a depth of approximately 8,500 feet to 10,114 feet KB. Injection is via a 4 ½-inch slotted liner in a 6 1/8-inch open hole. The current configuration of the well is illustrated in Figure 4.

Petrotek Engineering Corporation (Petrotek) supervised field data collection activities and evaluated the March 16, 2017 test data collected by Petroleum Pressure Surveys (PPS). The rate data and downhole pressure data are of reasonable quality and are sufficient to allow evaluation of reservoir pressure and calculation of a pressure sensitive permeability or skin threshold pressure. The test procedures, analytical methods, and results are presented in the following sections.

The data acquired indicate that the static bottomhole pressure of the comingled formation layers currently in communication to the wellbore was approximately 3,099 psia at 8,450 feet KB (8,437 feet BGL) at the time of the test. Temperature measured concurrently near the top of the injection interval prior to injection was approximately 256 degrees F. Static fluid level was found at approximately 1,279 feet KB and the static bottom hole pressure gradient measured in the well was approximately 0.367 psi/ft.

A step-rate injection test was conducted to examine short-term wellbore and reservoir behavior. During the early steps the reservoir accepts fluid on vacuum and with pressure changes due to rate increases that may be consistent with radial flow in porous media. The reservoir exhibits a significant change of pressure build-up character at a bottomhole injection pressure gradient of approximately 0.445 psig/foot between steps 5 and 6 based on the gauge test depth of 8,437 feet BGL. When injection pressures exceeded this pressure-sensitive permeability/skin gradient threshold during the test, the reservoir began to accept significantly more injection rate with decreasing incremental pressure build-up. It is likely that naturally occurring fractures which are already open upon initial injection propagate or dilate in some portion of the injection zone above this pressure threshold in conjunction with increasing rate and pressure.

## 2.0 RESERVOIR TESTING DATA COLLECTION AND ANALYSIS

### March 2017 Pressure Transient Data Collection

Test data were collected using pumping service company (Halliburton Energy Services) equipment to record rate and wellhead pressure. Downhole silicon memory tools set on slickline from PPS was used to record bottomhole temperature and pressure. The use of downhole gauges ensured maximum data quality and removed hydrostatic head changes due to variations in specific gravity along with estimates of friction loss in the tubing and surface equipment from analyses. This new well was completed in March 2017 and has not been used to inject Class II waste. A short-term constant-rate injection test was run the day before the step-rate test; the well had been in falloff monitoring for approximately 13 hours prior to the start of step-rate operations.

To conduct the reservoir testing, pumping and pressure measurement, equipment was rigged-up and pressure control equipment installed on the wellhead. Two percent KCl brine was used during testing.

After the falloff data collection period, the gauges were still at the test depth of 8,450 feet KB (8,437 feet BGL) and a stabilized static bottomhole pressure was recorded for approximately 1 hour. A stabilized pressure (3,102 psia) and temperature was established as baseline; a step-rate injection test was started by pumping at incrementally increasing rates. Initial injection started with approximately -16 psi of surface injection pump pressure. After 12 increasing rate steps, the test was terminated by stopping the pump and shutting in the well head with a final bottomhole injection pressure of 4,309 psia. The test data are summarized in Attachment 1 and Figure 1. Figure 4 presents the well configuration at the time of testing.

Each of the 12 injection steps were of approximate equal durations (30 minutes). As designed, the injection steps of approximately equal time length, but variable rate changes generated the step-like increases in pressure during the injection portion of the test. Some noise was present in the responses due to rate variations.

Based on flow rates recorded by the surface data logger, the average final injection rate step was 14.3 barrels per minute (bpm) or 600 gallons per minute (gpm). A cumulative injection volume of approximately 2,086 barrels was injected during the 6-hour step-rate injection period. A copy of the raw data collected by PPS with the field report is provided as Appendix 1.

### General Analysis Methodology

In addition to establishing original reservoir pressure, sufficient data were collected from the step-rate test to allow estimates of formation pressure sensitivity. Standard data analysis techniques were utilized to review the data. Although a valid test was conducted, the step-rate test data analysis was complicated due to several factors including changing

injection fluid temperature (displacement of hot formation brine followed by cooler produced brine water from the surface tanks), skin, natural fractures that may be open at original reservoir pressure and a slotted screen completion into multiple-layered formations.

Plots of pressure versus rate and time functions were applied to the step-rate evaluation. A variety of graphical analyses confirmed the pressure sensitive permeability or skin factor. Plots included Cartesian graphs to evaluate the relationship of data trends. Raw data were processed and plotted using the commercially available Excel spreadsheet package. It is noted that it is unlikely that any of the data reached completely stable radial flow during any of the testing.

**Reservoir Pressure**

Reservoir pressure was determined by obtaining a static gradient survey as the pressure transducer was run into the tubing. The well had only been shut-in for part of a day prior to this testing, so it is possible that some cross-flow was still occurring during the static monitoring period. A fluid gradient of approximately 0.433 psi/ft was measured in the tubing prior to starting the step-rate test. Static tubing fluid level was at approximately 1,279 feet KB and there was a negative wellhead pressure consistent with the gradient survey. At the test gauge depth of 8,437 feet BGL, injection zone pressure was measured as 3,099 psia (0.367 psi/ft). Figure 2 presents a plot of the wellhead pressure, bottom hole pressure and injection rate versus time.

**Step-Rate Injection Test**

Step-rate testing is accomplished by injecting fluid at a series of increasing rates and recording the resulting injection pressures. Constant rate injection during each step and equal time period steps contribute to accurate analysis. Downhole pressure measurement is preferred to eliminate the effect of tubular friction and variable specific gravity on the data. If fluid properties, formation permeability, wellbore skin, and other formation properties remain constant during a step-rate injection test, a plot of the pressures measured at the end of each equal duration step versus rate will yield a straight line. A reduction in the slope of the pressure versus rate line typically indicates an increase in permeability or reduction in skin. In many instances this increase is attributable to opening fractures in the injection formation (Earlougher 1977).

It is well documented that the pressure required to initiate a fracture in a new completion (breakdown pressure) can often be greater than the pressure required to open pre-existing fractures in a borehole on subsequent occasions. In the case where a well is initially broken down, fluid must overcome the stresses in the immediate vicinity of the wellbore and overcome the fracture toughness of the rock to initiate the break. After this has occurred or in cases where natural fractures exist within a reservoir, pressure must only reach a level (opening pressure) sufficient to overcome the stresses holding the rock together to open the pre-existing fracture. In naturally fractured reservoirs that have

fracture transmissivity at all reservoir pressures, apparent changes may be more difficult to assign to fracture opening since fractures may be open throughout a test.

As previously noted, the raw step-rate pressure data are presented in the PPS report included as Appendix 1 of the test report. As shown by the rate and pressure data plotted in Figure 1, slight rate variations occurred over each of the rate steps. Each rate step was approximately 0.5 hours, allowing classical analysis to be performed.

Figure 1 shows that a significant pressure increase is evident during each of the first five step rates. Steps 6 through 12 generally exhibit smaller relative pressure increases during each step, despite steps having significant incremental increases in injection rate. It appears that a portion of Step 6 likely takes place above a pressure sensitivity threshold. This is more clearly evident in Figure 3, which is a plot of bottom-hole injection pressure versus average rate sustained during each step. Note in this plot that the slope of the line fitted through final bottomhole pressures at the end of steps 1 through 5 is substantially different than the slope obtained by fitting a curve through the subsequent steps 7 through 11. The slope of the line from the final steps in this test has a significantly reduced slope as compared with any slope through the first test steps. All pressure is plotted for each step rate, showing the increasing pressure during each step.

Based on the reduction in slope observed in Figure 3 and review of the pressure versus time trace illustrated in Figure 2, the pressure data appears to reach a pressure sensitive permeability or skin threshold at bottom hole pressure range of 3,725 – 3,750 psi reached during step 6. By extrapolating the early and late step lines and plotting an intersection a value for the pressure sensitive threshold gradient based on the Cartesian analysis method occurs in the injection zone at a pressure of approximately (3,720 psig) (gradient of 0.441 psig/ft) at a reference depth of 8,437 feet BGL. It is possible that natural fractures in the injection zone contribute to the multi-layer permeability-thickness communicating to the well at all injection rates and pressures to differing degrees throughout the test.

## 3.0 CONCLUSIONS

The data collected during the testing were of sufficient quality to derive estimates of the current reservoir and wellbore parameters discussed in this report. Standard industry data collection and analysis procedures were followed with respect to this testing. Graphs of the data are provided that show the relationship of pressure versus time and pressure versus rate.

In summary, analysis of the data indicate that 1) the initial reservoir pressure gradient was approximately 0.37 psi/ft prior to injection, 2) there is a pressure sensitive injectivity threshold at which naturally occurring fractures dilate under current wellbore conditions in the injection zone at a bottomhole pressure gradient of approximately 0.445 psig/foot, and 3) there are naturally occurring fractures in the injection zone that are already open with a full column of fluid in the well. During injection at pressures above a gradient of 0.445 psig/foot, it appears that the skin factor decreases and/or the permeability increases to a stimulated value as compared with trends observed at the start of the test. The injection test data showed conclusive evidence of a changing permeability or skin factor that is pressure related.

# FIGURES

**Figure 3**
EWS 4 DJ Basin LLC
EWS No. 4A
March 2017 Step Rate Test

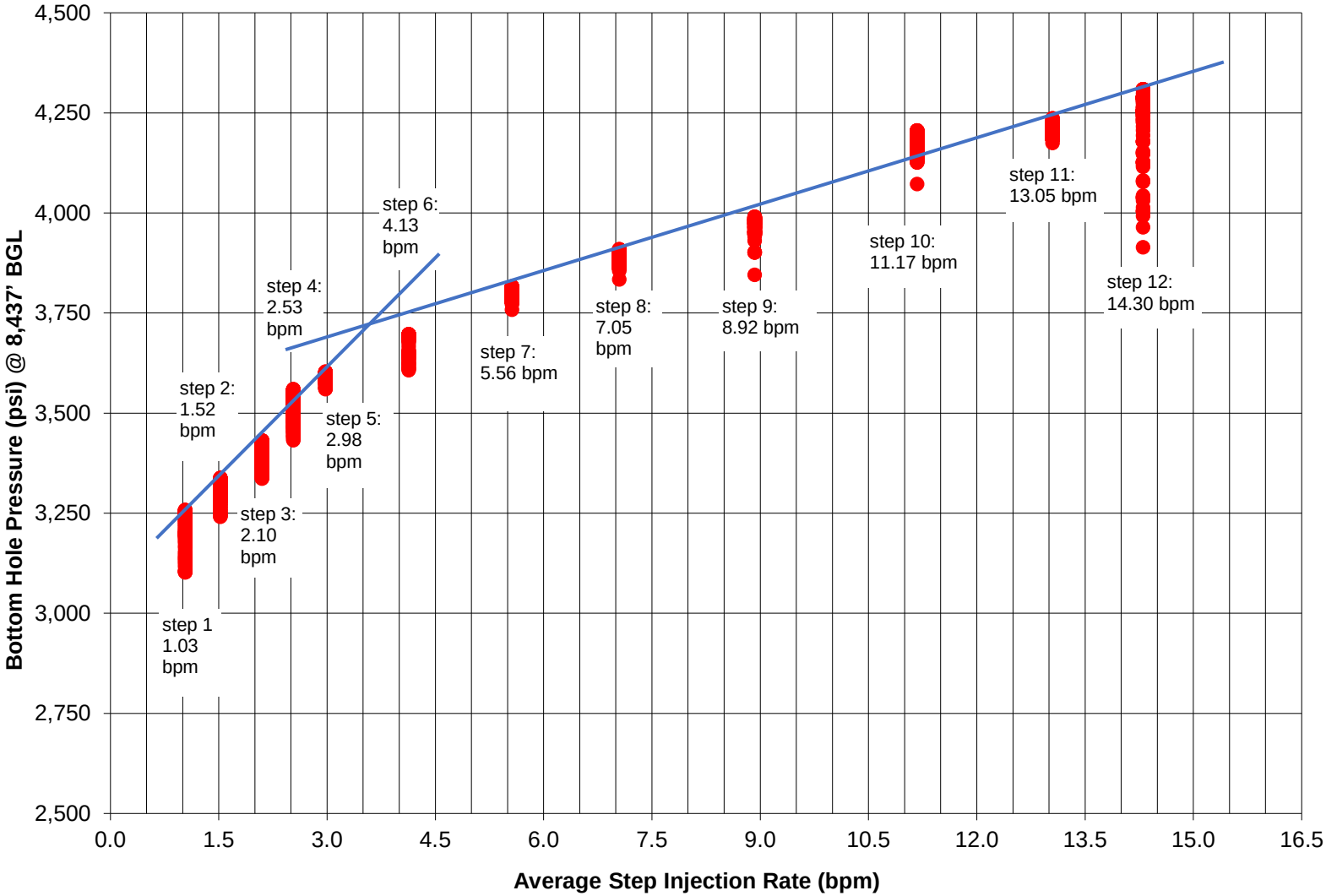


**Figure 1**
EWS 4 DJ Basin LLC
EWS No. 4A
March, 2017 Step Rate Test

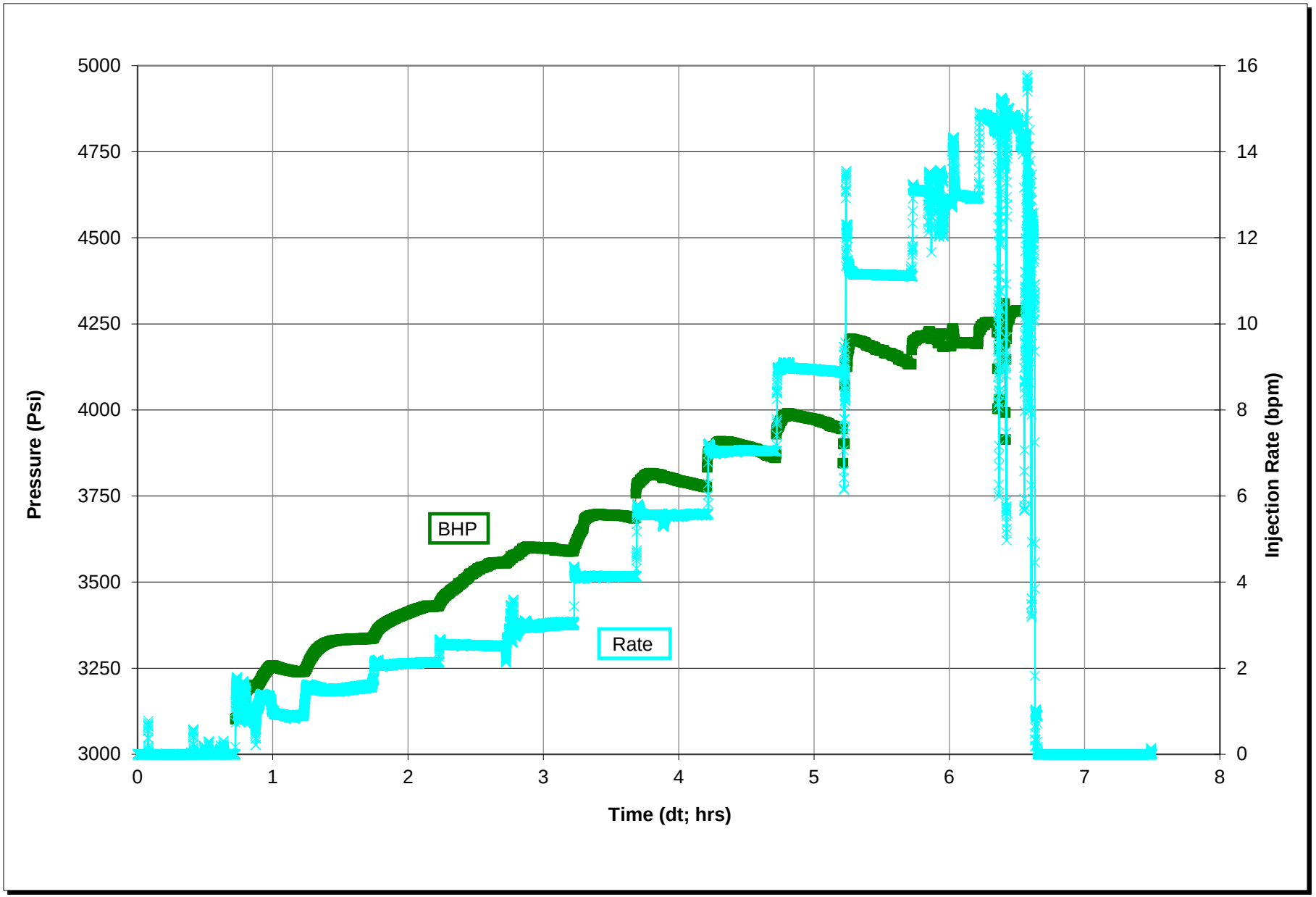
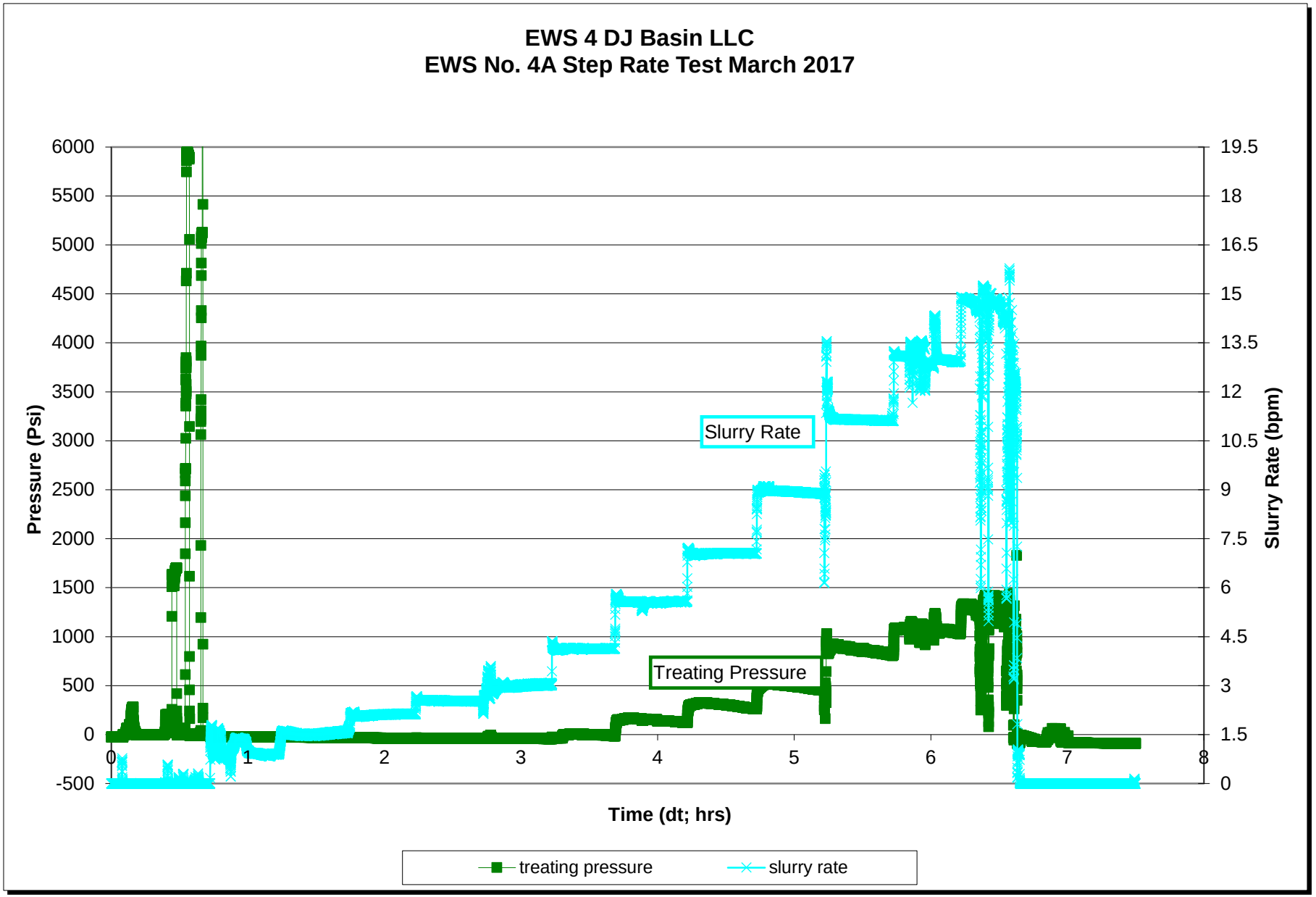
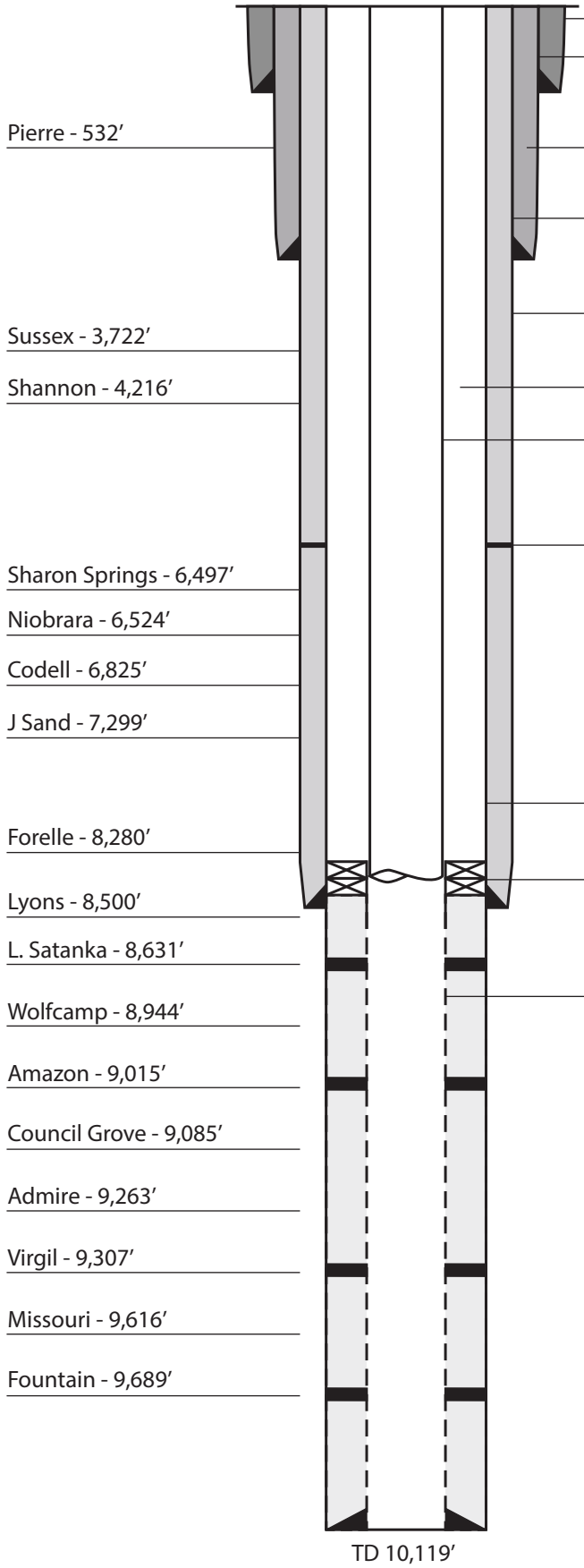


**Figure 2**


EWS 4 DJ Basin LLC
EWS No. 4A Step Rate Test March 2017
Pressure (Psi)
Slurry Rate (bpm)
Time (dt; hrs)
Slurry Rate
Treating Pressure
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
19.5
18
16.5
15
13.5
12
10.5
9
7.5
6
4.5
3
1.5
0
0
1
2
3
4
5
6
7
8
treating pressure
slurry rate




**EWS #4A**
**SENW, Sec, 17, T2N-R63W 6th PM**
**Weld County, CO**
**Lat. 40.13947 Long. -104.46355**

Note: All depths are TVD referenced to Kelly Bushing, 13 ft. above Ground Level.

Expedition Water Solutions

Wellbore Diagram
EWS #4A
Figure 4
2017 EWS No. 4A Drilling & Completion Report

| | | |
|---|---|---|
| Scale: NTS | Date: 02-23-2017 | |
| 01_EWS_No4A_Wellbore.ai | By: JLM | Checked: WJ |

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5935 South Zang Street, Suite 200
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# Appendix 1
## Bottomhole Step Rate Test Raw Pressure Data (PPS Field Data Report)

PETROLEUM PRESSURE SURVEYS

**Petroleum Pressure Surveys**
Sterling, CO 80751
104 Juniper Dr.

*Fax:* (970) 522-5240

*Cell:* (970) 520-9359

mkenney.pps@gmail.com

# Bottom-hole Pressure Report

| | |
|---|---|
| COMPANY: | Expedition Water Solutions Colorado, LLC |
| WELL: | EWS #4A |
| LOCATION: | Weld County, Colorado |
| DATE: | March 14-16, 2017 |

**Company:** EWS Colorado, LLC **State:** Colorado

**Well:** EWS #4A **County:** Weld

**Test Description:** Constant Rate Test/Falloff/Step-Rate Test

**Instrument Type:** 10K Silicon Crystal Electronic Probes

## Procedure Chronology

| | |
|---|---|
| **Gauges Energized** | 20:05 03-14-2017 |
| **Gauges in Lubricator** | 20:35 03-14-2017 |
| **Gauges on Bottom @ 8450' KB** | 21:42 03-14-2017 |
| **Start Pumping Constant Rate** | 07:08 03-15-2017 |
| **Well Shut In** | 19:10 03-15-2017 |
| **Start Pumping Step Rate** | 08:06 03-16-2017 |
| **Well Shut In** | 16:32 03-16-2017 |
| **Gauges off Bottom** | 17:50 03-16-2017 |
| **Gauges in Lubricator** | 18:36 03-16-2017 |

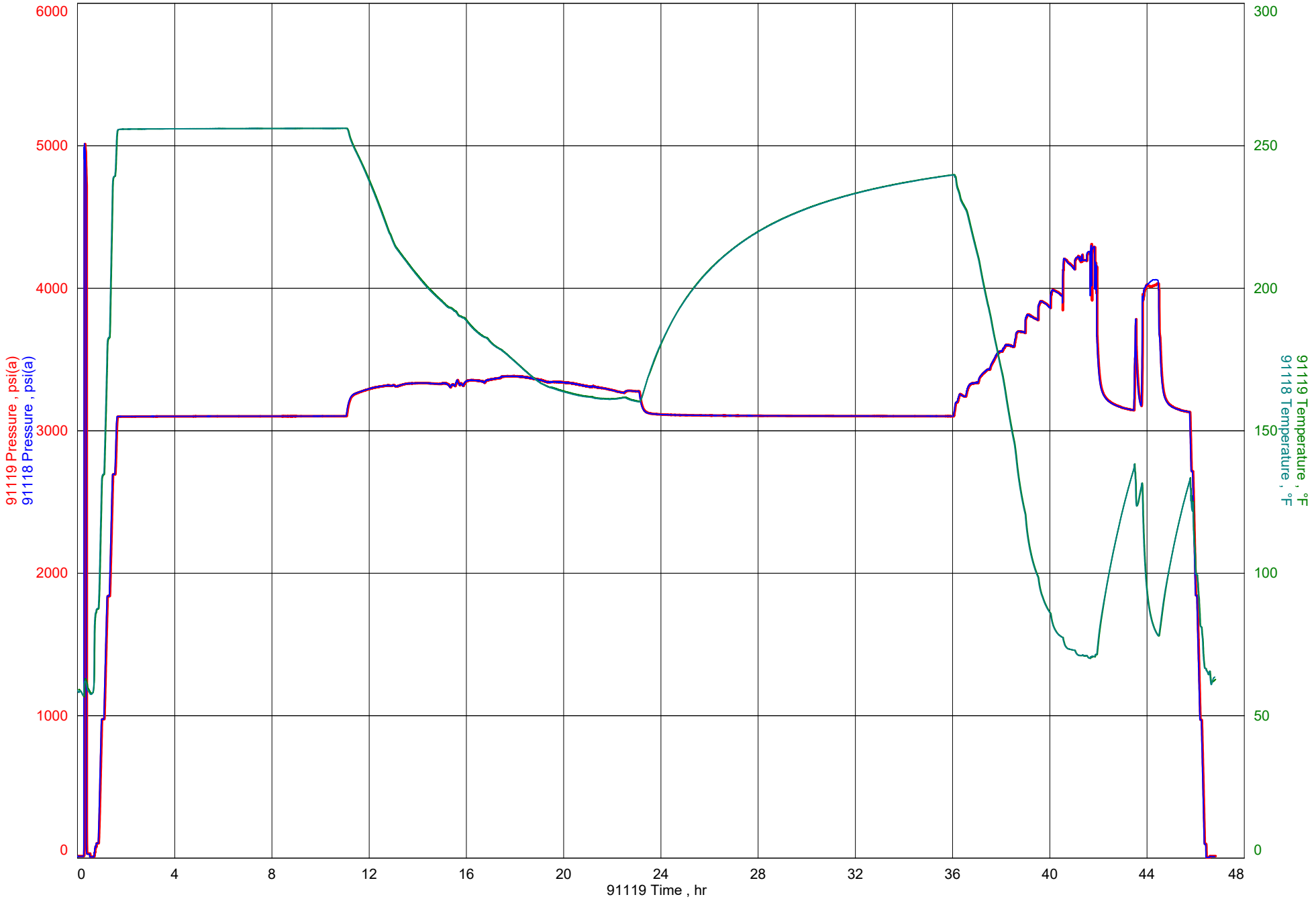
## Pressure/Temperature Information

| | |
|---|---|
| **Maximum Measured Pressure** | 5017.29 psia |
| **Maximum Measured Reservoir Temperature** | 256.15 deg F |

Expedition Water Solutions

# Cartesian

EWS #4A



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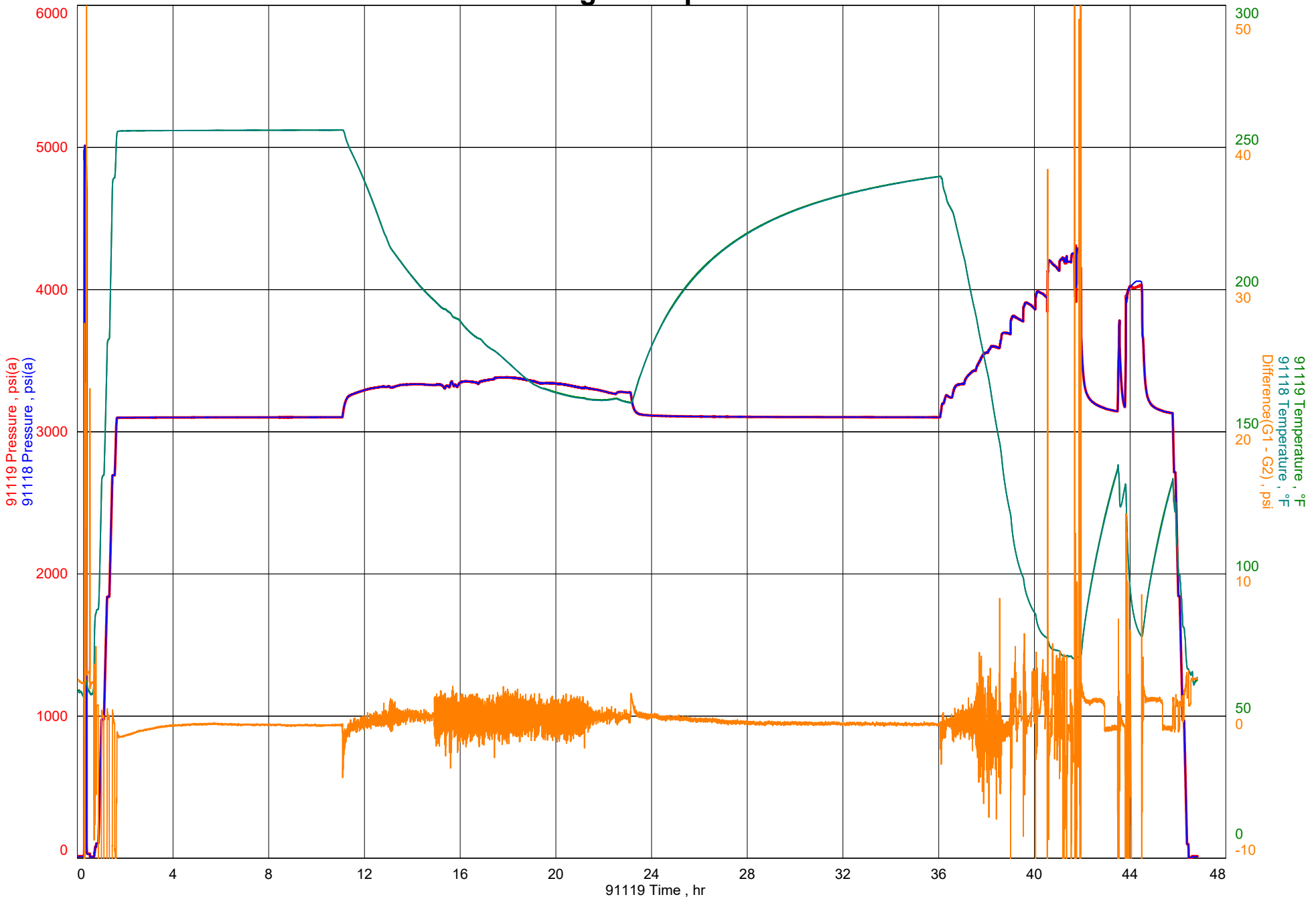
# Gauge Comparison

EWS #4A



# RIH Gradient

Expedition Water Solutions — EWS #4A

| | | | | | |
|---|---|---|---|---|---|
| Gauge Serial Number | 91119 | | Gauge Type | Silicon Crystal | |
| Gauge Manufacturer | CalScan | | Maximum Recorder Range | 10000.00 | psi |
| Run Depth (Log KB) | 8450.00 | ft | Date of Last Calibration | 2016/12/21 | |
| Gauge Start Date | 2017/03/14 20:06:00 | | Gauge Stop Date | 2017/03/16 18:53:00 | |
| Date Gauge On Bottom | 2017/03/14 21:42:00 | | Date Gauge Off Bottom | 2017/03/16 17:50:00 | |

**Test Data**

| | | | | | |
|---|---|---|---|---|---|
| Top(TVD KB) | | ft | Bottom(TVD KB) | | ft |
| Pool Datum Depth (SS) | | ft | Well Datum Depth | 8450.000 | ft |
| Tubing Pressure: Initial | 0.00 | psi(a) | Tubing Pressure: Final | 0.00 | psi(a) |
| Casing Pressure: Initial | 0.00 | psi(a) | Casing Pressure: Final | 0.00 | psi(a) |
| Start Test Date | 2017/03/14 | | Date Well Shut-In | | |

| Depth ft | Time hh:mm:ss | Duration min | Pressure psi(a) | Gradient psi/ft | Temp. °F | Gradient °F/ft |
|---|---|---|---|---|---|---|
| 0.00 | 20:40:00 | | 10.70 | | 57.94 | |
| | | | | 0.062 | | 0.020 |
| 1500.00 | 20:55:40 | 15.67 | 104.24 | | 87.51 | |
| | | | | 0.435 | | 0.024 |
| 3500.00 | 21:09:30 | 13.83 | 974.84 | | 134.71 | |
| | | | | 0.432 | | 0.024 |
| 5500.00 | 21:23:10 | 13.67 | 1839.06 | | 182.66 | |
| | | | | 0.427 | | 0.028 |
| 7500.00 | 21:36:40 | 13.50 | 2694.05 | | 239.38 | |
| | | | | 0.426 | | 0.017 |
| 8450.00 | 21:48:10 | 11.50 | 3098.67 | | 255.77 | |

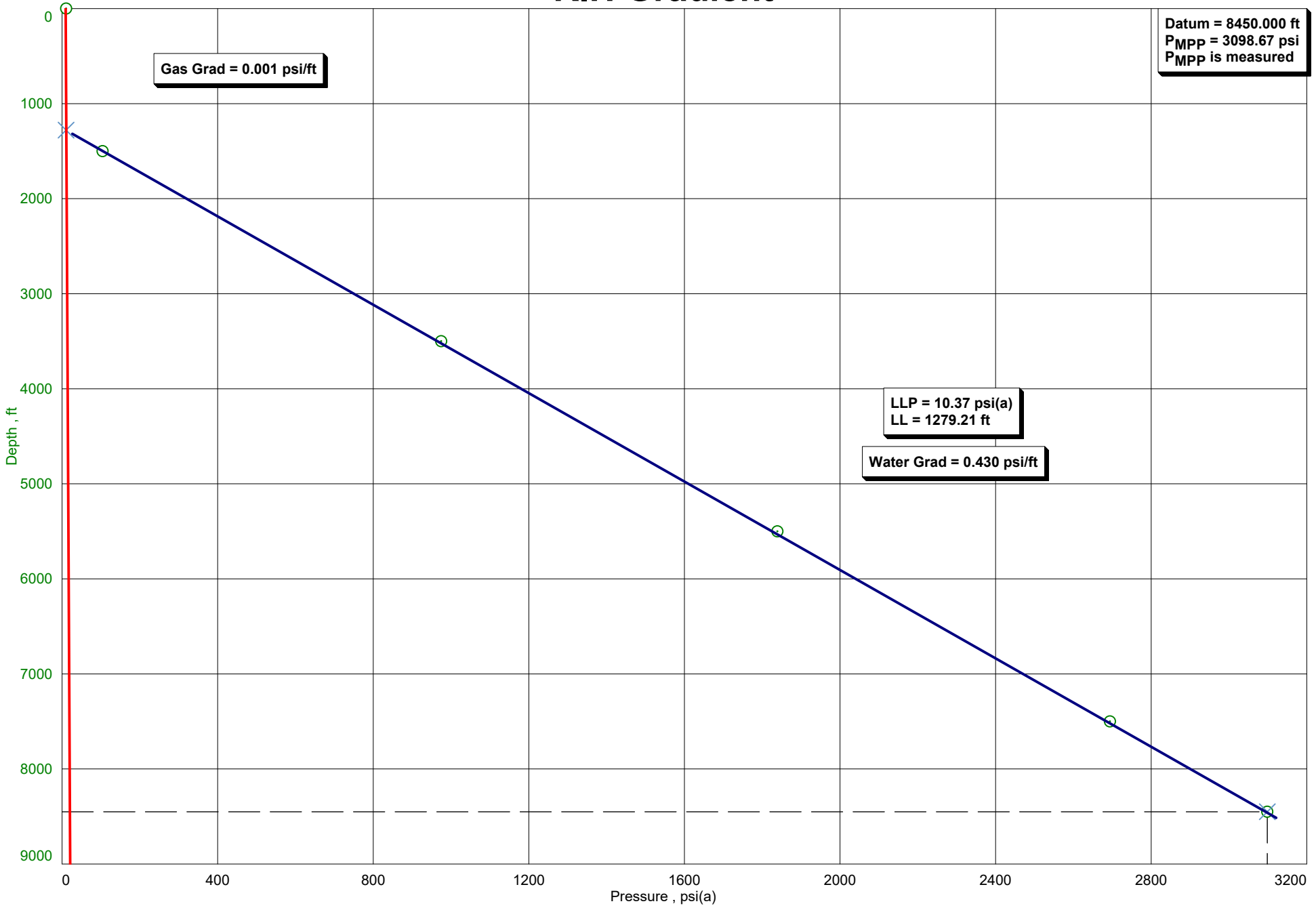
**Results**

| | | | | | |
|---|---|---|---|---|---|
| Gas | 0.001 | psi/ft | Gas - Water Interface | 1279.21 ft | 10.37 psi(a) |
| Water | 0.430 | psi/ft | | | |
| | | | **Well Datum Depth** | **8450.00 ft** | **3098.67 psi(a)** |

Expedition Water Solutions

# RIH Gradient

EWS #4A



# POOH Gradient

Expedition Water Solutions — EWS #4A

| | | | | | |
|---|---|---|---|---|---|
| Gauge Serial Number | 91119 | | Gauge Type | Silicon Crystal | |
| Gauge Manufacturer | CalScan | | Maximum Recorder Range | 10000.00 | psi |
| Run Depth (Log KB) | 8450.00 | ft | Date of Last Calibration | 2016/12/21 | |
| Gauge Start Date | 2017/03/14 20:06:00 | | Gauge Stop Date | 2017/03/16 18:53:00 | |
| Date Gauge On Bottom | 2017/03/14 21:42:00 | | Date Gauge Off Bottom | 2017/03/16 17:50:00 | |

**Test Data**

| | | | | | |
|---|---|---|---|---|---|
| Top(TVD KB) | | ft | Bottom(TVD KB) | | ft |
| Pool Datum Depth (SS) | | ft | Well Datum Depth | 8450.000 | ft |
| Tubing Pressure: Initial | 0.00 | psi(a) | Tubing Pressure: Final | 0.00 | psi(a) |
| Casing Pressure: Initial | 0.00 | psi(a) | Casing Pressure: Final | 0.00 | psi(a) |
| Start Test Date | 2017/03/14 | | Date Well Shut-In | | |

| Depth ft | Time hh:mm:ss | Duration min | Pressure psi(a) | Gradient psi/ft | Temp. °F | Gradient °F/ft |
|---|---|---|---|---|---|---|
| 8450.00 | 17:49:20 | | 3130.91 | | 132.85 | |
| | | | | 0.438 | | 0.012 |
| 7500.00 | 17:56:30 | 7.17 | 2715.04 | | 121.74 | |
| | | | | 0.436 | | 0.011 |
| 5500.00 | 18:07:00 | 10.50 | 1843.16 | | 99.29 | |
| | | | | 0.436 | | 0.009 |
| 3500.00 | 18:18:20 | 11.33 | 970.49 | | 81.09 | |
| | | | | 0.436 | | 0.007 |
| 1500.00 | 18:29:10 | 10.83 | 99.13 | | 66.53 | |
| | | | | 0.061 | | 0.001 |
| 0.00 | 18:37:20 | 8.17 | 7.04 | | 65.03 | |

**Results**

| | | | | | |
|---|---|---|---|---|---|
| Gas | 0.001 | psi/ft | Gas - Water Interface | 1263.93 ft | 0.91 psi(a) |
| Water | 0.436 | psi/ft | | | |
| | | | **Well Datum Depth** | **8450.00 ft** | **3130.91 psi(a)** |

Expedition Water Solutions

# POOH Gradient

EWS #4A